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Detection of (anti)symmetry and (anti)repetition: Perceptual mechanisms versus cognitive strategies

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ABSTRACT

Symmetry and repetition are recognized as cues in perceptual organization, but there is disagreement on whether they are detected automatically. This disagreement is resolved by noting that some studies mixed up shape regularities and shape antiregularities (i.e., symmetries and repetitions with mismatches in contour curvature polarity). The results of two experiments indicate that a task-irrelevant regularity is automatically picked up by the visual system, whereas a task-irrelevant antiregularity is not. This suggests that detection of regularities is part of the visual system's intrinsic encoding, whereas detection of antiregularities requires higher cognitive strategies involving selective attention.

1. Introduction

Detection of regularities such as symmetry and repetition is believed to be an integral part of the perceptual organization process that is applied to any visual input (cf. Tyler, 1994; van der Helm & Leeuwenberg, 1996; Wagemans, 1995). These regularities are therefore said to be visual regularities, that is, regularities the visual system is sensitive to. Mach (1886) and Pascal (1658/1950) already pointed this out, and later, the Gestaltists (Koffka, 1935; Köhler, 1920; Wertheimer, 1912, 1923) put symmetry and repetition forward as relevant cues in the perceptual grouping of stimulus elements into perceived objects. That is, as sustained by Corballis and Roldan (1974) and Treder and van der Helm (2007), symmetry seems to be a cue for the presence of one object, and repetition seems to be a cue for the presence of multiple objects. Relatively few empirical studies have been devoted to repetition, but symmetry has indeed been shown to play a relevant role in issues such as object recognition (e.g., Pashler, 1990; Vetter & Poggio, 1994), figure–ground segregation (e.g., Driver, Baylis, & Rafal, 1992; Leeuwenberg & Buffart, 1984), and amodal completion (e.g., Kanizsa, 1985; van Lier, van der Helm, & Leeuwenberg, 1994).

The foregoing suggests that detection of symmetry and repetition is part of the visual system's intrinsic encoding of stimuli. That is, it suggests that detection of symmetry and repetition occurs automatically, without requiring selective attention to match stimulus parts. This point, however, became the main issue in a debate in which Baylis and Driver (1995) argued that detection of repetition does require selective attention, while Koning and Wagemans (2009) argued that it does not. The latter study was also a reaction to Bertamini, Friedenberg, and Kubovy (1997) who, although they did not use the terms repetition and selective attention, drew basically the same conclusion as Baylis and Driver did. Resolving this issue is relevant because, as indicated above, it touches upon the very essence of what the perceptual organization process is believed to involve. Also in neuroscience, for instance, there is no consensus about whether or not perceptual organization requires attention (see, e.g., Lamme & Roelfsema, 2000, versus Gray, 1999).

In this article, we argue that Baylis and Driver and Bertamini et al. drew the wrong conclusion for the right reasons, while Koning and Wagemans drew the right conclusion for the wrong reasons. These studies investigated detection of regularity in designated sides of 2-D shapes, closed contours, and projections of slanted 3-D objects, respectively, and we argue that they mixed up perfect regularities and regularities with mismatches in contour curvature polarity. This may be explicated as follows.

Koning and Wagemans looked at symmetry and at what they called repetition but what we call antirepetition (see also Csathó, van der Vloed, & van der Helm, 2003). These features are, in terms of 2-D shapes, shown in Fig. 1a and d. Bertamini et al. also looked at only these two features, but they were careful enough to use the fairly neutral terms reflected contours and translated contours. At first sight, it may indeed seem just a matter of terminology, but as we argue in this article, it is much more than that. For in-

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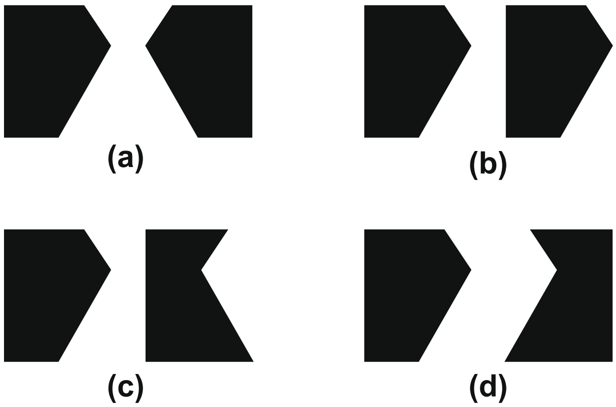

Fig. 1. Regularity and antiregularity in two 2-D shapes. (a) Symmetry: the facing sides of the shapes are symmetrical. (b) Repetition: the right-facing sides of the shapes are identical. (c) Antisymmetry: the right-facing sides of the shapes have opposite curvature polarities (i.e., convexities in one side correspond to concavities in the other side) and opposite contrast polarities. (d) Antirepetition: the facing sides of the shapes have opposite curvature polarities and opposite contrast polarities.

stance, one might think that, in Fig. 1d, the facing sides of the two shapes are identical and therefore exhibit repetition, but this is not the case. These facing sides have opposite contrast polarities at the image level, and currently more relevant, they have opposite curvature polarities (i.e., convexities in one side correspond to concavities in the other side) at the object level, that is, at the level of the perceived shapes. This is why we call it a case of antirepetition or, more generally, a case of antiregularity. Hence, we would say that Koning and Wagemans' and Bertamini et al.'s conclusions, though different, both applied to antirepetition and not, as they suggested, to repetition.

Notice that, in general, stimulus elements can be said to have values in various dimensions (e.g., position and colour), and that we define antiregularity as a form of perturbed regularity in which corresponding elements have opposite values in some dimension (which may imply that the stimulus remains symmetrical in other dimensions). For instance, as we return to in Section 4, if corresponding dots in an otherwise perfectly symmetrical dot pattern have opposite contrast polarities with respect to the background, then the stimulus is said to exhibit antisymmetry. Likewise, as indicated above, we also speak of antiregularity if corresponding contour elements have opposite curvature polarities.

Be that as it may, to get more clarity on the issue above, we performed experiments using a stimulus manipulation similar to the one introduced by Bertamini et al. and elaborated by Koning and Wagemans (the details of this manipulation are given below). Crucially, however, we added a condition involving what everybody would call repetition (see Fig. 1b), and to complete the design, we also added a condition involving what we call antisymmetry (defined analogously to antirepetition; see Fig. 1c). Using another stimulus manipulation (see also below), Baylis and Driver also considered these four stimulus conditions, but they pooled symmetry and antisymmetry under the term symmetry, and they pooled repetition and antirepetition under the term repetition. As we report in this article, however, we found clear qualitative differences between regularity and antiregularity, leading to fundamentally different conlusions than those three studies drew.

Baylis and Driver concluded that selective attention is involved in the detection of what they called repetition; as said, Bertamini et al. concluded the same, albeit in different words. This conclusion, however, applied to what we call antirepetition, and we found that it does not apply to what everybody would call repetition. Furthermore, Koning and Wagemans concluded that detection of what they called repetition is part of the visual system's intrinsic encoding. Also this conclusion, however, applied to what we call antirepetition, and we found that it only applies to what everybody would call repetition.

To be clear, the authors of those three studies were well aware of the occurrence of opposite curvature polarities in their stimuli. They seemed to argue, however, that these curvature polarities are opposite only at the object level and that, at the image level, one can yet speak of symmetry and repetition (the mismatched contrast polarities in case of 2-D shapes and 3-D objects seem to have been ignored alltogether). They further seemed to argue that one should frame perceptual questions in terms of the effect of image properties on the perceptual organization process which, after all, transforms images into perceived objects. This argument is only partly true, however. The perceptual organization process is not a uni-directional bottom-up process from images to objects but is a highly complex and combinatorial process which, for a given image, seems to search for the best-fitting object. This idea stems from the early 20th century Gestaltists (Koffka, 1935; Köhler, 1920; Wertheimer, 1912, 1923) and is nowadays commonly accepted in both cognitive science and neuroscience (see, e.g., Ehrenstein, Spillmann, & Sarris, 2003; Gray, 1999).

The foregoing implies that not only image properties but also properties of candidate objects are relevant to the perceptual organization process and that, therefore, such properties should also be taken into account in empirical designs and analyses (i.e., not just afterwards when discussing the data; see also Koning & van Lier, 2003, 2004, 2005, for convincing evidence that object-level properties may overrule image-level properties). This holds particularly for the kind of experiments considered here. As said, those three studies investigated detection of regularity in designated sides of 2-D shapes, closed contours, and 3-D objects, respectively. Here, designated means that, for each regularity separately, the participants knew not only which regularity they had to look for but also in which two sides they had to look for this regularity. Notice, however, that participants respond on the basis of what they perceive, that is, on the basis of the perceived objects with all their object-level properties. It is therefore plausible that object-level properties influence their responses. For instance, notice that, in Fig. 1, the antiregularities yield qualitatively different percepts than those yielded by the regularities.

The foregoing also reveals another methodological problem. That is, in order to perform the task, participants invoke selective attention to focus on the task-relevant sides of the objects they perceive (cf. Ahissar & Hochstein, 2004). This means that it is hard to claim that detection of a feature in the task-relevant sides does or does not require selective attention (which was the question to begin with). Therefore, we proceeded as follows.

2. Experiment 1

Considering the consistency of the data across those three studies, the stimulus type does not seem decisive, and just as Baylis and Driver, we chose to use stimuli consisting of 2-D shapes. Furthermore, as said, we considered a complete design with the four (anti)regularity conditions depicted schematically in Fig. 1. These conditions were also considered by Baylis and Driver, but they did not manipulate the task-irrelevant sides, whereas we did – in a way similar to what Bertamini et al. and Koning and Wagemans did, but they did not consider a complete design. To be more specific, Baylis and Driver used only straight task-irrelevant sides (as in Fig. 1), whereas we used random and congruent task-irrelevant sides (see Fig. 2). Here, congruent means that the task-irrelevant sides exhibited the same kind of (anti)regularity as the task-rele-

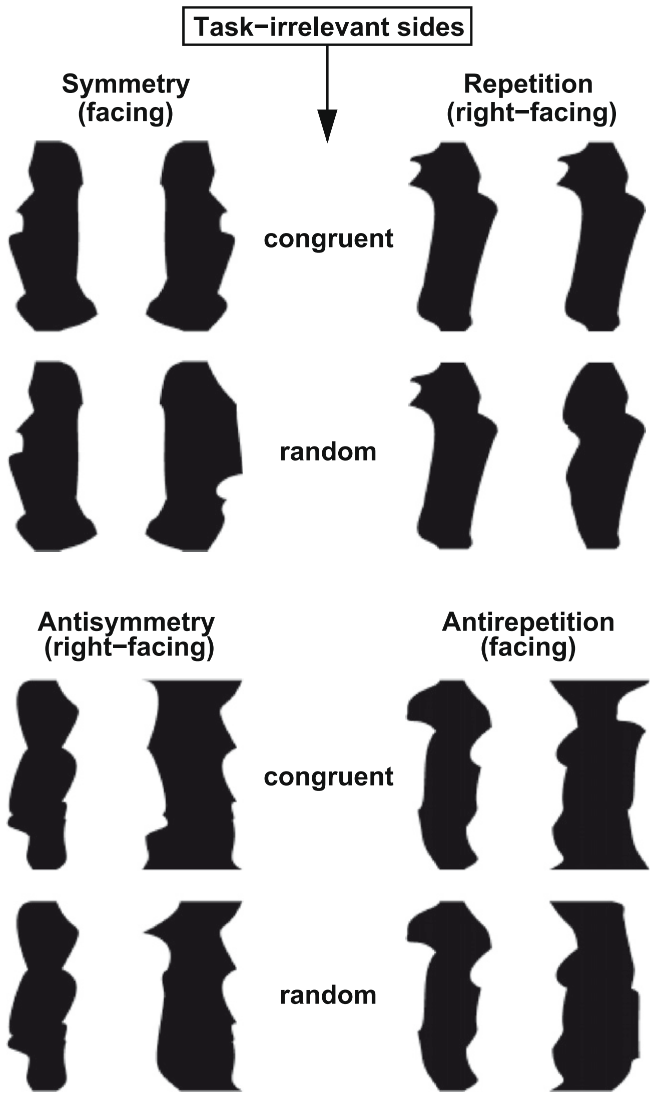

Fig. 2. Experimental conditions in Experiment 1. Participants had to discriminate random from "same" or "reflected" stimulus sides which were indicated as being relevant to the task (the facing sides for symmetry and antirepetition, and the right-facing or left-facing sides for repetition and antisymmetry). To get an optimal assessment of whether the visual system is sensitive to an (anti)regularity, task-irrelevant sides either were random or congruent, where congruent means that they exhibited the same kind of (anti)regularity as the task-relevant sides. This way, we in fact probed whether participants unconsciously picked up the task-irrelevant (anti)regularity (see our rationale in the text).

vant sides did. The rationale for this manipulation is as follows (see Section 4 for a theoretical underpinning).

In general, if the visual system is sensitive to a task-relevant feature, then the detection of this feature is bound to be facilitated by the presence of a congruent task-irrelevant feature (just as, in multiple symmetry, detection of a task-relevant axis is facilitated by the presence of the other axes; Nucci & Wagemans, 2007; Palmer & Hemenway, 1978; Royer, 1981; van der Vloed, 2005; Wenderoth & Welsh, 1998). Hence, in our stimuli, if a congruent task-irrelevant (anti)regularity yields a facilitating effect (compared to random task-irrelevant sides), then this can be taken as evidence that this task-irrelevant (anti)regularity is detected unconsciously, that is, as part of the visual system's intrinsic encoding and without requiring selective attention.

Notice that, unlike in those other three studies, this approach circumvents the methodological problem mentioned at the end of Section 1– even though, to participants, there were no differences in procedure and task (in both their and our experiments, the regularity conditions were blocked and participants had to detect "same" or "reflected" relationships between designated task-relevant stimulus sides). That is, those three studies were interested in quantitative differences in detection speed and detection accuracy between the (anti)regularities in the task-relevant sides, and participants were aware that this was at stake. Participants in our experiments also thought that this was at stake, but our interest actually was the qualitative question of whether or not they unconsciously benefitted from the congruent (anti)regularities in the task-irrelevant sides.

The latter is therefore also the question our statistical analyses focus on. That is, unlike in those three studies, our analyses do not elaborate on quantitative differences between the four (anti)regularities – partly because our stimuli are not suited to address this quantitative question (which requires, for instance, another control of the distances between task-relevant sides and between task-irrelevant sides), and partly because Baylis and Driver already did a good job in this respect (they found, in our terminology, that symmetry is better detectable than repetition, and that both are better detectable than the two antiregularities; see also Section 4). Two further differences are worth mentioning. Those three studies looked at (anti)regularity in one and two objects (we return to this in Section 4), whereas we looked at (anti)regularity in two objects only. Furthermore, for symmetry and antirepetition in two objects, Koning and Wagemans found quantitative but not qualitative differences between facing and nonfacing task-relevant sides, and we chose to use facing task-relevant sides only.

2.1. Method

2.1.1. Participants

Twenty-five undergraduate students participated in the experiment. They had normal or corrected-to-normal vision and received course credits for their participation.

2.1.2. Stimuli

Every stimulus consisted of two black hard-edge shapes on a white background (see Fig. 2). The luminance of the black and the white areas amounted to 0.33 cd/m^2 and 69.50 cd/m^2, respectively. Each shape was created by filling in a closed contour consisting of two horizontal straight lines connected by two vertical curves. Each curve consisted of five segments that were specified each by the cubic Bézier function

$$B(t) = (1-t)^3 \cdot P_0 + 3 \cdot t \cdot (1-t)^2 \cdot P_1 + 3 \cdot t^2 \cdot (1-t) \cdot P_2 + t^3 \cdot P_3$$

with $t \in [0, 1]$, and with control points P_1, P_2, P_3, and P_4. The curves had G^0 continuity, that is, adjacent Bézier segments were connected but did not share a common tangent at the connection point. To avoid very sharp curvatures in the curves, we maintained a minimum vertical distance of 0.44° visual angle (30 px) between both ends of a segment. Each curve was confined to a strip of 2° (80 px) width and 9.86° (400 px) height. The central block between the strips for the left-hand and right-hand curves had a width of 1.29° (50 px). The two shapes were separated by a gap of 2.57° (100 px) width.

We considered four kinds of (anti)regularity, namely, symmetry, repetition, antisymmetry, and antirepetition. In case of symmetry and antisymmetry, corresponding curves were reflected, and in case of repetition and antirepetition, they were translated. For each kind of (anti)regularity, there were two task-relevant sides and two task-irrelevant sides. For symmetry and antirepetition, the facing sides were task-relevant and the nonfacing sides were task-irrelevant. For repetition and antisymmetry, either the right-facing or the left-facing sides were task-relevant and the other sides were task-irrelevant.

For each kind of (anti)regularity, we considered four subconditions. First, the two crucial subconditions in which the task-relevant sides exhibited the (anti)regularity while the task-irrelevant sides were either random or congruent, that is, exhibited the same kind of (anti)regularity as the task-relevant sides (see Fig. 2). Second, two sorts of catch trials in which the task-relevant sides were random while the task-irrelevant sides either exhibited the (anti)regularity or were random. For each participant, a set of stimuli was randomly generated using custom MATLAB routines.

2.1.3. Procedure

A chinrest was used to ensure participants had a constant viewing distance of 60 cm, seated in front of a 19 in. monitor with a 100 Hz refresh rate and a resolution of 1280 × 1024 px. To prevent tearing artifacts, stimulus presentation was time-locked with the screen's vertical sync. Responses were recorded via a button box which allowed reaction times to be measured with a precision of 1 ms. Participants had to detect whether two designated task-relevant sides, which depended on the kind of (anti)regularity, were the same or reflected (they were not informed about our distinction between regularity and antiregularity). They were instructed to respond as quickly as possible, by pressing a "same" or "reflected" key with their dominant hand when they had detected such a relationship; otherwise, they had to press a "different" key with their nondominant hand.

The experiment was split into four blocks dedicated each to one of the four kinds of (anti)regularity. The order of the blocks was randomized across participants. At the beginning of each block, participants were informed about the relationship to be detected (same or reflected) and they were informed about which sides were task-relevant (by means of a written instruction on the screen, along with sample stimuli in which the two relevant sides in the current block were given by thick red lines). As said, for symmetry and antirepetition, the task-relevant sides were the facing sides. For repetition and antisymmetry, the task-relevant sides (left-facing or right-facing) were counterbalanced across participants.

Each block started with a practice phase of 32 trials, followed by an experimental phase of 120 trials. Each trial commenced with a central fixation dot presented for 600 ms. Following a blank screen lasting for 100 ms, the stimulus appeared and remained until a button was pressed. Auditory feedback was given if the response was wrong. The experiment was self-paced. In total, the experiment comprised 4 [(anti)regularities] × 4 [subconditions] × 30 [stimuli] = 480 experimental trials.

2.2. Results

Just as in the three studies we criticize, the catch trials merely served to keep participants focused on the task and were not analyzed further. Furthermore, all trials yielding a reaction time (RT) of less than 200 ms were removed. Before analysis, reaction time was turned into reaction speed by the reciprocal transformation 1/RT. The motivation was that reaction time distributions are skewed and that the reciprocal transformation yields more symmetrical distributions (as required for the application of most statistical models). For the speed analysis, outliers in each subcondition (i.e., values more than 2.5σ off mean) were removed. In addition to speed, we also investigated the effects of the experimental manipulations on accuracy in terms of percentage correct. As mentioned, for repetition and antisymmetry, left-facing and right-facing versions were balanced across participants. For the statistical tests, we pooled the data from these two groups because they did not differ significantly in terms of overall speed ($p = .274$) and accuracy ($p = .63$).

First, the data were analysed in 4 × 2 repeated measures ANOVAs. The first factor was the regularity in the task-relevant sides, comprising four levels (symmetry, repetition, antisymmetry, and antirepetition). The second factor was the congruency of the task-irrelevant sides, comprising two levels (congruent and random). For speed, we found main effects of both regularity and congruency, $F(3,22) = 31.116,\ p < .001$, and $F(1,24) = 39.857,\ p < .001$, respectively. The interaction was also significant, $F(3,22) = 10.551,\ p < .001$. For accuracy, we also found main effects of both regularity and congruency, $F(3,22) = 7.345,\ p < .001$, and $F(1,24) = 5.18,\ p < .05$, respectively. The interaction was also significant, $F(3,22) = 8.51,\ p < .001$.

Second, we used a-priori t-tests to investigate, for each (anti)regularity separately, the effect of congruency. For symmetry and repetition, speed was significantly higher in the congruent condition compared to the random condition, $t(24) = 4.617,\ p < .001$, and $t(24) = 7.005,\ p < .001$, respectively. For antisymmetry and antirepetition, we did not find significant differences ($p = .279$ and $p = .399$, respectively). Furthermore, for symmetry and repetition, also accuracy was significantly higher in the congruent condition compared to the random condition, $t(24) = 2.115,\ p < .05$, and $t(24) = 3.372,\ p < .01$, respectively. For antisymmetry and antirepetition, we did not find significant differences ($p = .638$ and $p = .076$, respectively). Hence, for symmetry and repetition but not for antisymmetry and antirepetition, participants responded both faster and more accurately when the task-irrelevant sides were congruent (see Table 1 and Fig. 3).

2.3. Discussion

The significant main effects and interactions we found for regularity and congruency indicate that these factors are perceptually relevant. As said, however, for each (anti)regularity separately, we were interested mainly in whether or not congruent task-irrelevant sides have a facilitating effect on its detectability in the task-relevant sides. We found that a task-irrelevant regularity indeed facilitates the detection of a congruent feature in the task-relevant sides, but that a task-irrelevant antiregularity does not.

This indicates that regularity, even though it is task-irrelevant, is yet picked up by the visual system, whereas antiregularity is

Table 1
Results of Experiment 1.

Regularity	Irrelevant sides	RT (ms)	Speed (1/RT)			Accuracy (%correct)		
		Mean	Mean	Std. err.	Diff.	Mean	Std. err.	Diff.
Symmetry	Random	653.6	1.530	.057		94.5	1.3	
	Congruent	624.5	1.601	.055	$p < .001$	97.5	.6	$p < .05$
Repetition	Random	846.4	1.182	.040		92.8	1.1	
	Congruent	771.0	1.297	.046	$p < .001$	96.8	.6	$p < .01$
Antisymmetry	Random	984.9	1.015	.054		92.1	1.7	
	Congruent	961.6	1.040	.064	$p = .279$	91.5	2.5	$p = .638$
Antirepetition	Random	685.6	1.459	.064		97.7	.6	
	Congruent	694.0	1.441	.053	$p = .399$	96.4	.7	$p = .076$

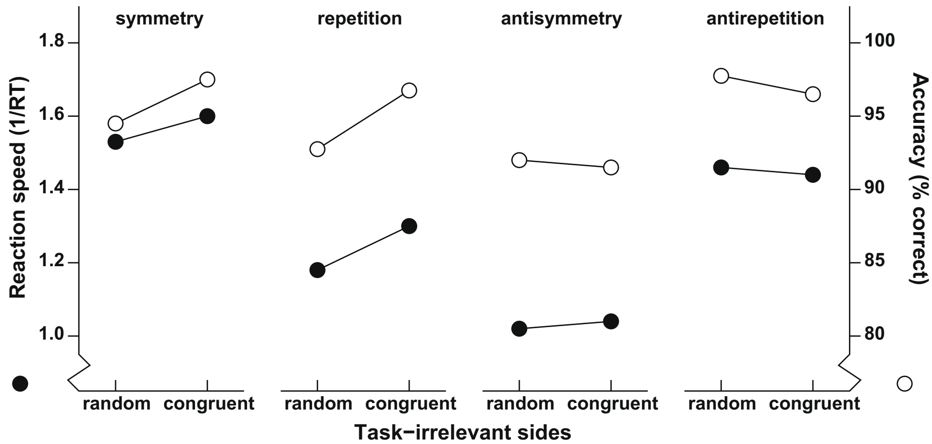

Fig. 3. Results of Experiment 1. The objective was not to investigate quantitative differences between the (anti)regularities but to investigate, for each of them separately, the qualitative question of whether its detection in the task-relevant sides is facilitated by a congruent (anti)regularity in the task-irrelevant sides. In terms of both speed (one divided by reaction time (RT) in seconds) and accuracy (percentage correct), congruent task-irrelevant sides yielded significant facilitating effects for symmetry and repetition, and no significant effects for antisymmetry and antirepetition (see also Table 1).

not. Hence, it suggests that detection of regularity is part of the visual system's intrinsic encoding, whereas detection of antiregularity is not. It suggests further that detection of antiregularity requires higher cognitive strategies involving selective attention (we return to this in Section 4).

Considering that the task-irrelevant parts in symmetry gave rise to a facilitating effect even though they were the most eccentric parts, the absence of such an effect for antisymmetry and antirepetition cannot be attributed to the distances between the task-irrelevant parts. Yet, the reflection axes for task-irrelevant sides and task-relevant sides coincide in symmetry but not in antisymmetry. Similarly, the translation distances between task-irrelevant sides and task-relevant sides are equal in repetition but not in antirepetition. One might argue that this in itself could explain the absence of an effect for antisymmetry and antirepetition. To control for this, we conducted the following experiment.

3. Experiment 2

3.1. Method

Unless stated otherwise, the method was identical to the method in Experiment 1.

3.1.1. Participants

Thirty-one undergraduate students participated in the experiment. They had normal or corrected-to-normal vision and received course credits for their participation. None of them had participated in Experiment 1.

3.1.2. Stimuli

The stimuli were identical to the stimuli used in Experiment 1, except that the widths of stimulus parts were modified to ensure that the distance between the reflection axes for the task-relevant and task-irrelevant sides was equal in symmetry and antisymmetry (see Fig. 4). Likewise, the modification ensured that the difference in translation distance for task-relevant and task-irrelevant sides was equal for repetition and antirepetition. To this end, the width of the left-hand and right-hand strips was decreased to 1.54° (60 px). Furthermore, for symmetry and repetition, the width of the central block was decreased to zero in the left-hand shape (so that the end points of the contour curves join) and was increased to 3.09° (120 px) in the right-hand shape. For antisymmetry and antirepetition, the width of the central block in both shapes was decreased to zero.

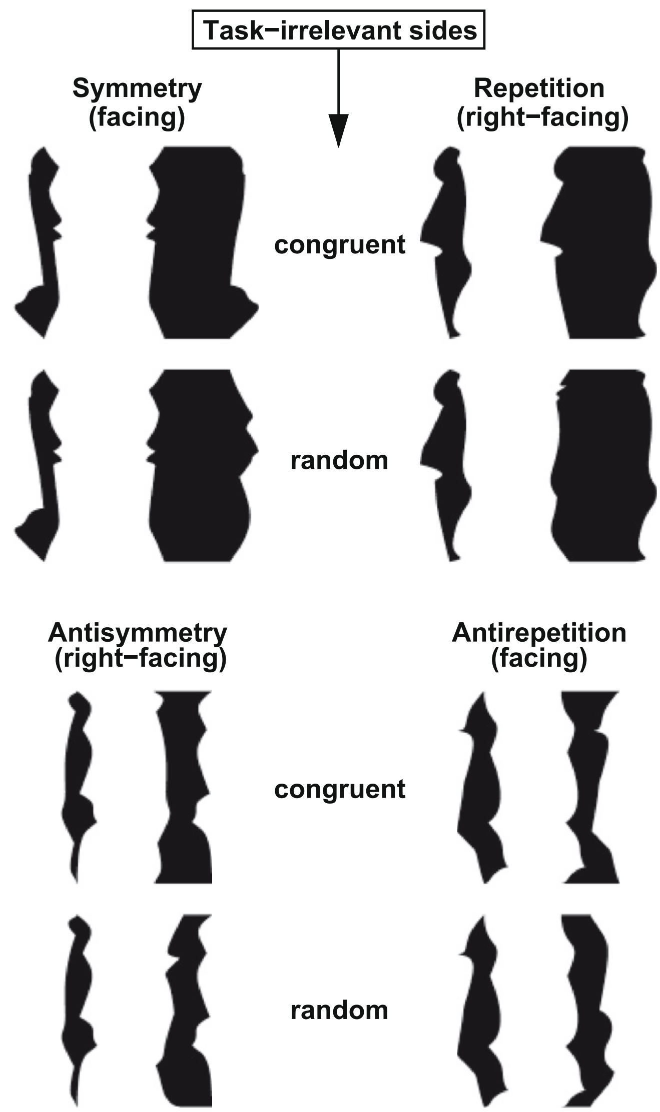

Fig. 4. Experimental conditions in Experiment 2. The design was the same as in Experiment 1, but this time, the widths of stimulus parts were modified to ensure that, for symmetry and antisymmetry, the distance between the reflection axes for the task-relevant and task-irrelevant sides was equal, and that, for repetition and antirepetition, the difference in translation distance for the task-relevant and task-irrelevant sides was equal.

3.2. Results

First, under the same conditions as in Experiment 1, the data were analysed in 4×2 repeated measures ANOVAs. For speed, we found a main effect of regularity, $F(3,28) = 21.498,\ p < .001$. There was no main effect of congruency ($p = .842$), but interaction was significant, $F(3,28) = 6.616,\ p < .01$. For accuracy, we found main effects of both regularity and congruency, $F(3,28) = 6.262,\ p < .01$, and $F(1,30) = 9.261,\ p < .01$, respectively. The interaction was also significant, $F(3,28) = 3.393,\ p < .05$.

Second, we again used a-priori t-tests to investigate the effect of congruency for each (anti)regularity separately. For symmetry and repetition, speed was significantly higher in the congruent condition compared to the random condition, $t(30) = 2.521,\ p < .05$, and $t(30) = 2.221,\ p < .05$, respectively. For antisymmetry, there was no significant effect of congruency ($p = .317$). For antirepetition, there was a significant effect of congruency, $t(30) = 3.2,\ p < .01$, but compared to symmetry and repetition, it was in the opposite direction (i.e., participants responded faster for random task-irrelevant contours). Furthermore, for symmetry and repetition, also accuracy was significantly higher in the congruent condition compared to the random condition, $t(30) = 2.227,\ p < .05$, and $t(30) = 3.529,\ p < .001$, respectively. For antisymmetry and antirepetition, there were no significant differences ($p = .130$ and $p = .580$, respectively). Hence, again, for symmetry and repetition but not for antisymmetry and antirepetition, participants responded both faster and more accurately when the task-irrelevant sides were congruent (see Table 2 and Fig. 5).

3.3. Discussion

As said, our stimuli were designed specifically to investigate, for each (anti)regularity separately, the qualitative question of whether or not congruent task-irrelevant sides have a facilitating effect on its detectability in the task-relevant sides. This time, we perturbed the global regularity in the regularity conditions, to make it harder to include the task-irrelevant sides. Yet, basically, we found the same pattern of results as in Experiment 1. We again found a facilitating effect in case of symmetry and repetition and not in case of antisymmetry and antirepetition. This strengthens the idea that detection of regularity is part of the visual system's intrinsic encoding, whereas detection of antiregularity is not.

Notice that, by the rationale given earlier, only a positive effect of congruency can be taken as evidence that the visual system is sensitive to the (anti)regularity at hand. Hence, the negative effect of congruency on speed we now found for antirepetition cannot be taken as such evidence (also notice that negative congruency effects were found neither in Experiment 1 nor by Koning & Wagemans, 2009). We think that this negative congruency effect, just as the lack of further effects of congruency for antiregularities, is due to a higher cognitive strategy using selective attention to match stimulus parts. In the next section, we go into more detail on such higher cognitive strategies, but we think that this negative congruency effect is to be attributed to the small width of the stimuli involved (see Fig. 4). Due to this small width, participants are faced with two nearby exemplars of what they are looking for, which may slow down such a higher cognitive strategy.

Table 2
Results of Experiment 2.

Regularity	Irrelevant sides	RT (ms)	Speed (1/RT)			Accuracy (%correct)		
		Mean	Mean	Std. err.	Diff.	Mean	Std. err.	Diff.
Symmetry	Random	617.5	1.620	.062		93.0	.9	
	congruent	600.8	1.665	.062	$p < .05$	95.3	.9	$p < .05$
Repetition	Random	826.4	1.210	.053		88.2	2.5	
	congruent	803.4	1.245	.051	$p < .05$	93.1	2.1	$p < .001$
Antisymmetry	Random	958.8	1.043	.097		84.6	2.4	
	congruent	993.6	1.006	.075	$p = .317$	87.6	2.6	$p = .130$
Antirepetition	Random	674.4	1.483	.062		93.6	1.3	
	congruent	699.3	1.430	.059	$p < .01$	93.1	1.3	$p = .580$

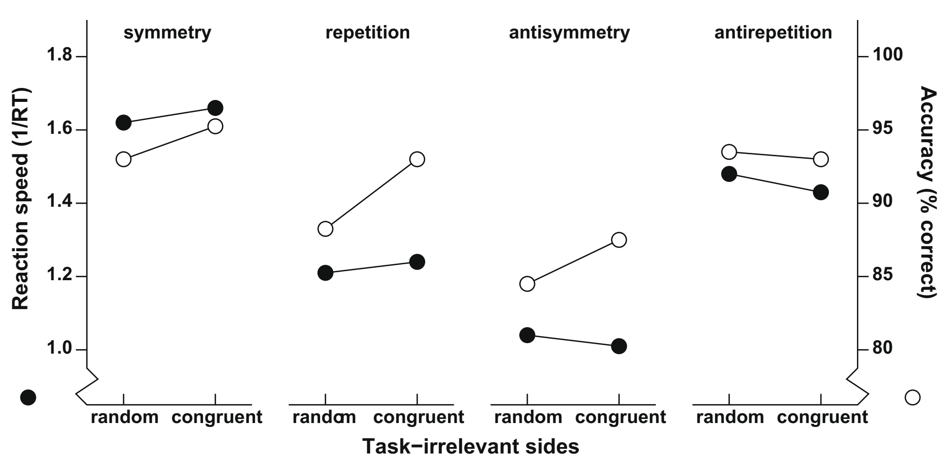

Fig. 5. Results of Experiment 2. In terms of both speed (one divided by reaction time (RT) in seconds) and accuracy (percentage correct), congruent task-irrelevant sides yielded significant facilitating effects for symmetry and repetition. There were no significant effects for antisymmetry and, only in terms of speed, a significant but negative effect for antirepetition (see also Table 2).

4. General discussion

The results of our experiments confirm the relevance of the distinction between regularity and antiregularity: a task-irrelevant regularity facilitates the detection of a congruent feature, whereas a task-irrelevant antiregularity does not. In Fig. 6, we summarized our results in terms of congruency effects as given by participants' performance in case of congruent task-irrelevant sides minus their performance in case of random task-irrelevant sides. This figure shows a clear qualitative difference between regularities and antiregularities: for symmetry and repetition, all congruency effects are significant positive effects, whereas for antisymetry and antirepetition, all congruency effects are nonsignificant except for one negative effect. This suggests that detection of symmetry and repetition is part of the visual system's automatic encoding of stimuli, whereas detection of antisymmetry and antirepetition is not. In other words, our results suggest that symmetry and repetition are visual regularities, whereas antisymmetry and antirepetition are not.

Our finding agrees with Mancini, Sally, and Gurnsey (2005) finding for an entirely different stimulus type, as follows. Saarinen and Levi (2000), Tyler and Hardage (1996), Wenderoth (1996), and Zhang and Gerbino (1992) investigated antisymmetry in stimuli consisting of separate elements (dots or blobs), that is, symmetry in which corresponding elements had opposite contrast polarities (see Fig. 7a). They found merely a minor detectability disadvantage for antisymmetry relative to symmetry, if at all. Mancini et al. argued that there are indeed spatial filters (and maybe neural analogs) which filter out positional information only and which thereby, in this stimulus type, cancel the difference between symmetry and antisymmetry (notice that this would imply that the antisymmetrical nature of these stimuli is not picked up by the visual system). To test this, they turned to checkerboard stimuli in which symmetry and antisymmetry are defined on the contrast dimension alone (see Fig. 7b). For these stimuli, they did find significant differences in detectability between symmetry and antisymmetry. They concluded therefore that symmetry and antisymmetry do not generally involve similar detection mechanisms and that, unlike symmetry, antisymmetry seems to require the involvement of selective attention – just as we conclude for the form of antisymmetry in the stimulus type we considered.

Notice that, in both antisymmetry stimuli in Fig. 7, there is a perceptual grouping by colour (which, in symmetrical displays, seems to affect detectability; Morales & Pashler, 1999). However, compared to the dot stimulus in Fig. 7a, the checkerboard stimulus in Fig. 7b gives rise to an additional grouping of checkerboard squares into spatially contiguous areas of homogeneous colour (which, in symmetrical displays, also seems to affect detectability; Huang & Pashler, 2002). Hence, here too, object-level properties seem to be the cause of the differences in detectability (see our discussion on this point in Section 1).

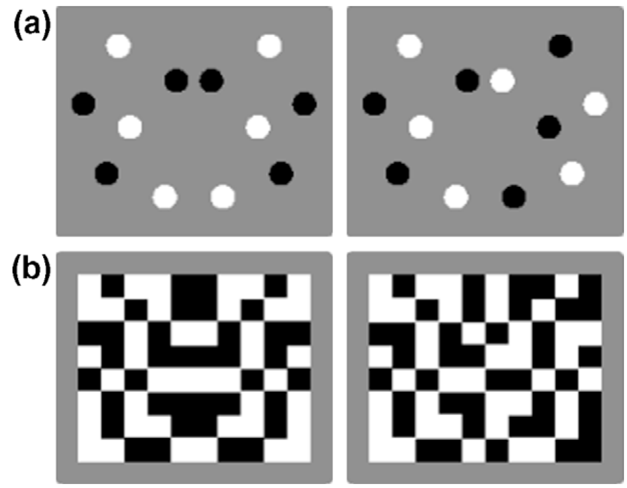

Fig. 7. Symmetry and antisymmetry in (a) dot patterns and (b) checkerboard patterns. In both cases, the antisymmetries arise because symmetrically positioned elements have opposite contrast polarities. In checkerboard patterns, the antisymmetry is detected less easily than in dot patterns (see text for an explanation).

Before we go into more detail on the visual system's intrinsic encoding in case of regularity and the higher cognitive strategies in case of antiregularity, it is expedient to re-evaluate the three studies we criticise. Therefore, next, we revisit these three studies, but now using our distinction between regularity and antiregularity.

4.1. Re-evaluating the literature

The study by Baylis and Driver (1995) involved four experiments in which, in designated task-relevant sides of one or two 2-D shapes, participants had to discriminate random structures from what they called symmetry and repetition. In all conditions, the task-irrelevant sides were straight. Stated in our terminology, they focused in their first three experiments on symmetry in one object, and on antisymmetry and (facing and nonfacing) symmetry in two objects. In their fourth experiment, they focused on antirepetition in one object, and on repetition and (facing) antirepetition in two objects.

In their final analysis, they summarized their results as depicted schematically in Fig. 8a. This picture suggests that they replicated

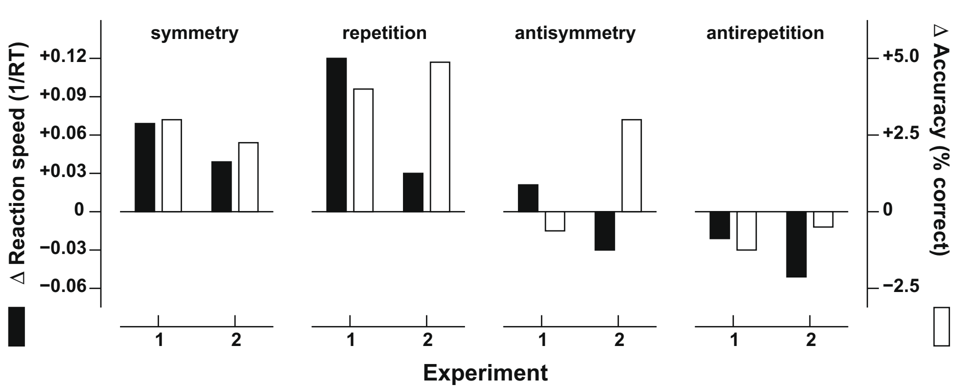

Fig. 6. Summary of the results of Experiments 1 and 2, in terms of congruency effects (participants' performance in case of congruent task-irrelevant sides minus their performance in case of random task-irrelevant sides). For symmetry and repetition, all congruency effects are significant positive effects, whereas for antisymmetry and antirepetition, all congruency effects are nonsignificant except for one negative effect (see also Tables 1 and 2).

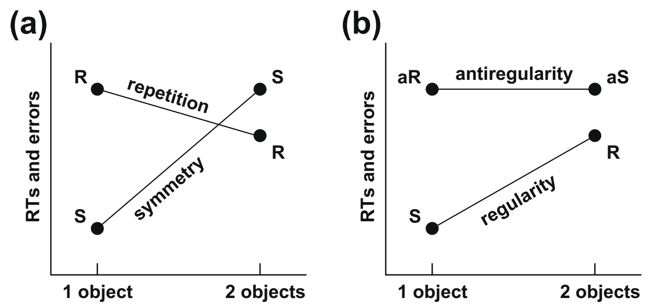

Fig. 8. (a) Sketch of Baylis and Driver (1995) summary of their results, which (wrongly) suggests that they replicated Corballis and Roldan (1974) finding that symmetry (S) is better detectable in one object, whereas repetition (R) is better detectable in two objects. (b) Baylis and Drivers repetition in one object was antirepetition (aR) and their symmetry in two objects was antisymmetry (aS), so that their results actually tell another story, namely, that symmetry is better detectable than repetition and that regularity is better detectable than antiregularity.

the results Corballis and Roldan (1974) found for symmetry and repetition in dot patterns (namely, that symmetry is better detectable in one object, whereas repetition is better detectable in two objects). However, if one honours the distinction between regularity and antiregularity, Baylis and Driver's results yield a fundamentally different picture (see Fig. 8b). This other picture reveals that they (a) replicated the well-known finding that symmetry is better detectable than repetition is (Bruce & Morgan, 1975; Corballis & Roldan, 1974; Julesz, 1971; Mach, 1886; Zimmer, 1984) and (b) found that regularity is better detectable than antiregularity is.

The difference between Fig. 8a and b shows that our distinction between regularity and antiregularity has fundamental implications for a proper understanding of the data. For instance, Baylis and Driver concluded that repetition is detected by a process of mental imagery involving what they called a jig-saw-matching strategy. Using closed-contour stimuli, Bertamini et al. (1997) investigated this process of mental imagery more deeply and concluded that it involves what they called a lock-and-key-matching strategy. Both ideas, however, make more sense if one realizes that they do not apply to repetition but to antirepetition. That is, in fact, both ideas (a) do not affect the status of repetition, and (b) support the hypothesis that antirepetition is not a feature the visual system is sensitive to, so that its detection requires a higher cognitive strategy.

In a follow-up study using projections of slanted 3-D objects, Koning and Wagemans (2009) looked, in our terminology, at symmetry and antirepetition in facing and nonfacing task-relevant sides of two objects and, crucially, they varied the task-irrelevant sides (in all conditions, these sides could be random, symmetrical, or antirepeated). Their main finding was that detection of facing and nonfacing symmetry is affected by the task-irrelevant structures, whereas detection of facing and nonfacing antirepetition is not. Notice that we not only replicated this finding but also included antisymmetry and repetition, leading to the broader finding that detection of regularity is facilitated by a congruent task-irrelevant structure, whereas detection of antiregularity is not.

Hence, we would say that also Koning and Wagemans' results (a) do not affect the status of repetition, and (b) support the hypothesis that antirepetition is not a feature the visual system is sensitive to, so that its detection requires a higher cognitive strategy. They, however, argued differently. First, and we agree on this point, they argued that it is preferable to have one account for symmetry and repetition, namely, a structural account which capitalizes on the visual system's intrinsic encoding. Then, however, they argued that this structural account predicts an effect of task-irrelevant structures for symmetry but not for repetition (this should explain they found no effect for what they called repetition). We do not agree with this point. They found no effect for what was actually antirepetition, so, there is neither reason nor need to try to explain this the way they did. Furthermore, our results clearly show that things are different than Koning and Wagemans seemed to believe: they predicted no effect for what they called repetition, but we found an effect for what everybody would call repetition. Indeed, we think it is logically more consistent to interpret this structural account as predicting that both symmetry and repetition are affected by task-irrelevant structures. This is sustained in the next subsection.

4.2. The visual system's intrinsic encoding

The foregoing re-evaluation shows that all three studies mixed up repetition and antirepetition, which led to their usage of incomplete designs and analyses. As we mentioned in Section 1, they seemed to argue that one should frame the problem in image-level terms, that is, not in the object-level terms in which we defined antiregularity. As we also mentioned, however, it is nowadays commonly accepted in both cognitive science and neuroscience that the perceptual organization process is not a uni-directional process from images to objects but a highly combinatorial process which, for a given image, seems to search for the best-fitting object. As said, this implies that also object-level properties are relevant to the perceptual organization process.

One account of what the best-fitting object is for a given image, is that it is the simplest object among all fitting objects (Hochberg & McAlister, 1953; Leeuwenberg, 1969, 1971; Leeuwenberg, van der Helm, & van Lier, 1994; van der Helm, 2000, 2004). In this account, an object is simpler the more regularity it exhibits – that is, of course, regularity the visual system is sensitive to. This simplicity account implies that, in our experiments, the difference in participants' performance between the random and congruent subconditions can be explained by the difference in complexity between the stimuli in these subconditions. This is in fact precisely our underlying idea in arguing that, compared to a random task-irrelevant structure, a congruent task-irrelevant feature facilitates the detection of a task-relevant feature – at least, if both features are features the visual system is sensitive to.

Hence, by giving an underpinning of our rationale rather than an alternative account, this simplicity account indeed explains the positive congruency effects we found for symmetry and repetition. By the same token, it suggests that the lack of positive congruency effects for antisymmetry and antirepetition implies that these antiregularities indeed are not features the visual system is sensitive to.

Related to this simplicity account, by the way, is the so-called holographic approach which, based on a mathematical formalization of regularity, provides a fairly comprehensive explanation of visual regularity detection (van der Helm & Leeuwenberg, 1991, 1996, 1999, 2004; see also Csathó et al., 2003, Csathó, van der Vloed, & van der Helm, 2004; Nucci & Wagemans, 2007; Treder & van der Helm, 2007; Wenderoth & Welsh, 1998). Among other things, it explains the earlier-mentioned phenomenon that symmetry is better detectable than repetition is. Here, we do not elaborate on the latter explanation, but it is relevant to note that it is based on the different perceptual structures which symmetry and repetition have according to this mathematical formalization (see Fig. 9; for details, see van der Helm & Leeuwenberg, 1996). This difference in perceptual structure also corroborates the earlier-mentioned idea that symmetry is a cue for the presence of one object and that repetition is a cue for the presence of multiple objects (Treder & van der Helm, 2007; see also Corballis & Roldan, 1974). The three studies just re-evaluated related their findings to this idea and they indeed corroborated it insofar as symmetry is

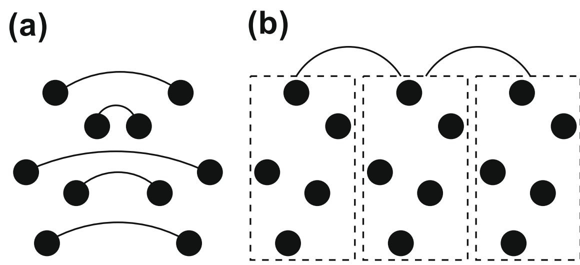

Fig. 9. Holographic structure of symmetry and repetition (the arcs depict the identity relationships a regularity is composed of). (a) Symmetry has a so-called point structure constituted by many identity relationships between elements; this suggests a high weight of evidence for symmetry (and, thereby, a high detectability) and a strong binding of the stimulus into one object. (b) Repetition has a so-called block structure constituted by few identity relationships between repeats; this suggests a low weight of evidence for repetition (and, thereby, a low detectability) and a segmentation of the stimulus into the repeats.

concerned, but because they mixed up repetition and antirepetition, they clouded it insofar as repetition is concerned.

One might argue that this idea about object cues could backfire. After all, in our symmetry condition, the symmetry of the white area between the two black areas might trigger an unintended figure–ground reversal so that this white area becomes, perceptually, the object that is judged by participants (see Figs. 2 and 4). Indeed, we think that, in general, figure–ground coding should be taken into account. However, as we argue next, we do not think it plays an interfering role in the issues addressed here.

This figure–ground argument can hardly be raised against the other conditions and would apply just as well to the three studies just re-evaluated – so, it would not invalidate our arguments against these three studies. Furthermore, in the stimuli considered here, such a figure–ground reversal neither turns regularities into antiregularities nor vice versa – so, it would not invalidate our distinction between regularities and antiregularities. Moreover, if a figure–ground reversal would play a role in the symmetry condition so that the central white area becomes the object that is judged, then there is hardly any reason to expect an effect of the task-irrelevant sides, as we nevertheless did find. Finally, neither Baylis and Driver (1995) nor Koning and Wagemans (2009) found qualitatitive differences between facing and nonfacing symmetry in two objects – such differences would be expected if facing symmetry triggers a figure–ground reversal.

4.3. Cognitive strategies in case of antiregularity

Although this article focuses mainly on the perceptual question of whether (anti)regularities play a role in the automatic perceptual organization process, it is expedient to also discuss the higher cognitive matching strategy which seems to be applied to detect antisymmetry and antirepetition. We think this matching strategy involves a form of mental translation. Just as Baylis and Driver (1995) jig-saw matching and Bertamini et al. (1997) lock-and-key matching in case of antirepetition, mental translation is a variation on the umbrella theme coined mental rotation (Shepard & Metzler, 1971). There is not much direct evidence for the idea of mental transformations (Bertamini, Friedenberg, & Argyle, 2002) but, here, we use the term mental rotation merely to refer to "what happens during the execution of a matching task". It indeed applies to a set of still poorly understood phenomena but, for instance, matching entire stimuli is known to be influenced by the perceptual structure of these stimuli (e.g., Shepard & Metzler, 1971; Pylyshyn, 1973; Koning & van Lier, 2004; van Lier & Wagemans, 1998). That is, mental rotation operates on structured object-level representations of stimuli rather than on stimulus-analogous image-level representations. In the experiments considered here, however, participants were asked to match stimulus parts rather than entire stimuli, and this suggests the following.

We think that, in the antiregularity conditions, participants perform mental translation on the stimulus parts to be matched (some of our participants in fact reported spontaneously that they applied a cognitive strategy in these conditions). Also then, however, it is expedient to realize that participants perform their task starting from the objects they perceive. This implies that they have to ignore willfully the objects they perceive and that they have to focus attention on the parts to be matched (cf. Ahissar & Hochstein, 2004). Such a strategy will therefore hardly be affected by task-irrelevant parts – as corroborated by the lack of positive congruency effects in our antiregularity conditions.

Notice that the foregoing does not explain that performance in the antirepetition condition is good compared to performance in the other three (anti)regularity conditions (see Figs. 3 and 5). We are reluctant, however, to draw conclusions from our results regarding quantitative differences between the four (anti)regularities. After all, as said, our stimuli are not suited to address these quantitative differences, and the difference we found in participants' treatment between the regularity and antiregularity conditions makes us even more reluctant. Yet, on repeated request, we allow ourselves to say the following.

The quantitative difference between symmetry and repetition, on the one hand, probably simply reflects the genuinely perceptual phenomenon discussed earlier, namely, that symmetry is detected more easily than repetition is. The quantitative difference between antisymmetry and antirepetition, on the other hand, is probably due to two factors related to the strategy above, which give facing antirepetition in two objects an advantage over antisymmetry. First, compared to antirepetition, the matching by mental translation in antisymmetry seems to require a more piecemeal treatment of the task-relevant sides. Second, and probably more relevant, the task-relevant sides have to be compared across an object in case of antisymmetry and only across a gap in case of facing antirepetition.

For instance, for nonfacing antirepetition in one object, the task-relevant sides also have to be compared across the object, and for this case, Baylis and Driver (1995) found no quantitative difference with respect to antisymmetry (see Fig. 8b). Furthermore, facing antirepetition in two objects has an advantage over nonfacing antirepetition not only in one object (as found in all three studies we re-evaluated) but also in two objects (Koning & Wagemans, 2009). This too suggests that, in case of antiregularity, comparisons across gaps are easier than comparisons across objects. Our study does not provide an explanation for this, but it does suggest that an explanation is to be searched for in terms of cognitive strategies rather than in terms of perceptual mechanisms.

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